

# Chapter III.

## ELECTRIC VEHICLES

### A. Introduction

The other alternative to powering our vehicles comes in the form of electricity and electric drive trains. This is, once again, a familiar energy source that most of us are aware and familiar with. While many people consider vehicles that run on electricity as being exotic, the reality is that electric vehicles have been around as long as ICE vehicles over 100 years ago.

This section explores the benefits, hazards, and infrastructures that support each of these electric vehicle types including zero emission vehicles (all electric), hybrid electric vehicles, hybrid electric buses and fuel cell technologies.

Electric vehicles provide many air quality benefits in that; they have no tailpipe emissions, no emission control equipment, like catalytic converters, PCV (positive crankcase ventilation), valves or oxygen sensors. There is no equipment to fail or deteriorate in use. This means that vehicles will always have zero emissions.

Electrical power plants that generate electricity used to charge electric vehicles do have air emissions. But these power plants must also meet stringent emission standards that are easier to monitor than millions of vehicles on the road. Analysis has shown that when considering the increased power plant emissions attributable to electric vehicles. Electric vehicles are still more than 90 percent cleaner than the cleanest petroleum technologies that are now becoming commercially available.

To imagine this technology in the context of our daily lives, we must first understand the technology itself. How do electric vehicles operate? What are their safety considerations? What do you need to know about electricity, its storage, and charging systems? Can you imagine yourself, confronted with an electric vehicle emergency and being able to deal with it effectively and safely? We will address questions like these in this section.

In the mid-nineteen nineties when California initiated the zero emission mandate there was an expectation that thousands of all electric vehicles would populate American roadways. Original equipment manufacturers, like General Motors and Toyota, lead the way to an all electric vehicle future in their EV-1 and RAV-4 vehicles. These vehicles



*A young woman at the turn of the century demonstrates the ease of charging the electric vehicle.*



*The safety of charging an electric vehicle is demonstrated with a little girl on a rainy day charging the families EV-1.*



*Neighborhood electric vehicles fill a niche in our choice of transportation*

were taken out of production when California withdrew the Zero emission mandate.

Today, most electric vehicles have been relegated to neighborhood electric vehicles that get up to 35 miles at a top speed of 30 miles per hour. Improvements to battery technology may bring a re-birth of electric vehicles in the near future. The electric vehicle technology that was developed a decade ago is the same high voltage system that is in use with the neighborhood electric, hybrid electric vehicles and the fuel cell vehicles we see today. The information is transferable to all types of electric vehicle power-trains. This section forms the foundation of information for other electric vehicle discussions that will follow.

## **B. ELECTRIC VEHICLE TECHNOLOGY**

In many ways, electric vehicles are very similar to internal combustion vehicles. Some of the electric vehicles, like the Chevy Volt, are being developed and designed from the ground up, using special materials and design practices to reduce vehicle weight and increase the vehicles aerodynamics. Other electric vehicles are adaptations of an internal combustion vehicle style with the power train replaced with an electric power-train.

So what are the similarities and differences between an internal combustion vehicle and an electric vehicle? Many of the safety features are the same such as air bags, power steering and antilock braking systems. Many materials like paints, coatings, glasses, plastics, upholstery, metals, wiring, insulation, rubber, and others are the same as those on internal combustion vehicles. But that is where the similarity ends.

The primary differences between the two vehicle types include a battery pack instead of a fuel tank, an electric motor instead of a internal combustion engine, high and low voltage systems instead of just low voltage, and an electronic control module instead of an ignition system to name a few. What we need to know is how an electric vehicle operates, how each of the components inter-relate, and how all of this effects our emergency response.

### **Battery Properties**

A battery consists of five major components: electrodes, separator, terminals, electrolyte, and a case or enclosure. There are two terminals per battery, one negative and one positive. The electrolyte can be a liquid, gel, or solid material. Traditional batteries such as lead acid (Pb Acid), Nickel Cadmium (NiCd), and others have used a liquid electrolyte. The electrolyte may be either acidic or alkaline depending on the type of battery. In the Advanced Sealed Lead Acid and Nickel Metal Hydride



*Ready for delivery, the Phoenix truck, Phoenix SUV, and the Tesla roadster. Are each all electric vehicles or ZEV's.*

batteries the electrolyte can also be in the form of a gel and/or suspended in a glass mat.

In the most basic terms, the battery is an electrochemical cell in which an electric potential (voltage) is generated at the battery terminals by a difference in potential between the positive and negative electrodes. When an electrical load such as a motor is connected to the battery terminals, an electric circuit is completed and current is passed through the motor generating the torque.

Outside the battery, current flows from the positive terminal through the motor, and returns to the negative terminal. As the process continues, the battery delivers its stored energy from a charged to a discharged state.

If the electrical load is replaced by an external power source that reverses the flow of the current through the battery, a battery can be recharged. This process is used to reform the electrodes to their original chemical state or full charge.

### Lead Acid Batteries

The lead acid battery is the most common choice for powering the initial fleet of electric vehicles. It is a mature technology that predates the development of the automobile and is universally used in internal combustion vehicles. In addition to maturity, other attractive features of the lead acid battery include a large manufacturing, distribution, service, and recycling infrastructure; low cost; compatibility with rapid charge; reliability; and, reduction of environmental problems. In its advanced, recombinant, valve-regulated configuration the electrolyte is immobilized, the container sealed, and the issues of electrolyte spillage and hydrogen and oxygen gas emissions during normal operation are eliminated.

The electrode of an electrochemical cell where oxidation, or the loss of electrons, takes place is defined as the anode (Pb). The electrode where reduction, or the gain of electrons, takes place is defined as the cathode (PbO<sub>2</sub>). In the lead acid battery, oxidation and reduction occur respectively at the positive and negative electrodes when charging, and at the negative and positive electrodes respectively when discharging. For simplicity, we will reference the anodes and cathodes as positive and negative electrodes.

The positive electrode of a lead acid battery consists of a lead grid that is covered with lead oxide. The negative electrode is essentially lead with an inert expander that causes the surface to be porous. These electrodes are interspersed and electrically insulated from one another with an inert separator. The electrolyte is sulfuric acid (H<sub>2</sub>SO<sub>4</sub>) which may be a



*Lead acid batteries are fairly easy to maintain in fleet operations, like school and other mass transit vehicles.*

liquid solution in flooded cell designs, or immobilized in an absorptive glass mat, or suspended in a gel in valve regulated designs.

The electrical potential between the positive and negative electrode is about 2 volts. This varies with temperature, the state of the charge, and whether or not the cell is being charged or discharged. During discharge, the voltage decreases as the state of charge decreases. As the battery approaches a state of full discharge, the exchange of electrons from the positive and negative electrodes continues until both are covered with lead sulphate and are at equal electrical potential. This is referred to as a discharged cell. Typically, when the cell voltage reaches approximately 1.5 volts, the cell should be recharged.

During the charging process, the reactions occur in the opposite direction to reform both electrodes back to lead and lead oxide respectively. As reformation proceeds, the electrical potential of the cell is returned to its original value of approximately 2 volts. During charging, the battery can enter a state of overcharge where the electrodes will give off-gasses in the form of oxygen from the positive electrode and hydrogen from the negative electrode. In conventional, free flowing electrolyte batteries, the gasses bubble through the electrolyte to the surface and out of the battery. This results in the electrolyte level in the battery dropping, necessitating water being added to maintain the operability of the battery.



*Sealed" or "Valve regulated" lead acid batteries are becoming in the norm in most vehicles on the road today.*

Over the last couple of decades, significant advances have been made to lead acid batteries. Development of advanced, recombinant valve regulated lead acid batteries has eliminated off-gassing and electrolyte level changing. The electrolyte is absorbed in a glass mat between the electrodes. Because of this, gasses generated during overcharge are prevented from bubbling away. This allows sufficient time for the gasses to recombine into water and sulfuric acid.

These types of lead acid batteries, however, still have a regulated valve in the event there is some type of abnormal condition such as charger run away where an excessive overcharge of the battery may occur. In a scenario where uncontrolled amounts of hydrogen and oxygen gas are generated inside the battery, venting is allowed.

Technological advances in lead acid battery technology, has resulted in greater cycle life and higher available energy. New charging systems monitor the cell voltage and stop the charging in order to prevent the cell voltage from reaching the levels where gas liberation occurs. Ventilation systems for charging rooms will no longer be needed.

These advanced lead acid batteries will be common in light duty cars, vans, and pickups. Unfortunately, due to cost constraints associated with large numbers of advanced batteries, heavy duty busses may still



rely on conventional lead acid batteries. Consequently, for heavy-duty vehicle charging stations, ventilation will be required.

Vehicle manufacturers have tested vehicles submerged in water with some interesting results. They report off-gasses of hydrogen and oxygen create “mini-burst” that are restricted to the battery compartment. The phenomenon sounds like a crackling noise. These tests show that there is no immediate threat to emergency personnel operating around submerged electric vehicles. In these tests, no lethal voltages were reported around the vehicle, vehicle frame, or to the test dummies in the driver and passenger seats.”

### Nickel Metal Hydride

Nickel Metal Hydride (NMIH) batteries have been available for consumer products for several years. NMIH batteries have higher performance (life cycle, specific energy, and energy density) than advanced lead acid. Because of this, NMIH batteries has been the next type of battery developed and commercialized for electric vehicle applications.

The electrolyte in NMIH batteries is 30 percent by weight potassium hydroxide in water. Therefore, the electrolyte is a base compared to the acid electrolyte of lead acid batteries. In many ways, NMIH batteries are similar to NiCd. Specifically, NMH and NiCd both use an aqueous alkaline electrolyte and a nickel hydroxide cathode. Unlike NiCd, NMH batteries do not use toxic cadmium for the anode. NMH uses a metal alloy capable of storing hydrogen formed at the anode during charging, and releasing the hydrogen during discharge. These metal alloys eliminate the potential health hazard associated with cadmium. Also, these alloys have higher energy storage capacities than cadmium.

NMH batteries operate at ambient temperatures and are also sealed like the advanced lead acid and valve regulated batteries. The nominal cell voltage for NMH batteries is 1.2 volts. The hydrogen is absorbed and stored in the metal hydride in a solid hydride phase as opposed to a gas.

During a discharge/charge cycle, there is no net change in electrolyte quantity or concentration in NMH. The constant concentration maintained in the NMH battery electrolyte results in better battery performance compared to NiCd batteries where the electrolyte concentration varies. Better performance is indicative of lack of off-gassing during normal operation, high and low temperature operations, and a longer life cycle of the battery.

NMH batteries are also more tolerant of overcharge and over discharge than many other types of batteries. During overcharging, the nickel hydroxide cathode becomes fully charged and begins generating oxygen. This oxygen recombines with hydrogen at the anode to form water and



*General Motors tested the EV-1 in a submerged tank to demonstrate that electricity will not escape and harm occupants or emergency responders while working n the water.*



*The Sanyo Nickel Metal Hydride Battery is currently used in all Ford vehicles*

heat. At low charge rates, the battery can keep up with the oxygen generation and recombination cycle. However, at high charge rates, oxygen can be produced faster than the anode can recombine it resulting in internal cell pressure buildup. Once the pressure reaches a certain value, the valves will open and vent the oxygen to the outside of the battery. The advanced charging systems developed for electric vehicle applications monitor the battery voltage to prevent the generation of gasses during charging.

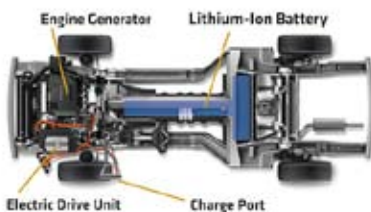
### Lithium Ion

The third battery type likely to be commercialized for electric vehicle applications is lithium-ion. Early press releases suggest that the Chevy Volt will be using Lithium-ion batteries. Because lithium is the metal with the highest negative potential and lowest atomic weight, batteries using lithium have the greatest potential for attaining the technological breakthrough which will allow electric vehicles the greatest performance characteristics in terms of acceleration and range.

Lithium metal is highly reactive with air and most liquid electrolytes. Lithium powder can even ignite spontaneously in air. Solid lithium metal ignites at temperatures above 180°C (356°F), and can have explosive or violent reactions with compounds containing sulfur, metal oxides, titanium trioxide, and vanadium pentoxide. To avoid these problems associated with metal lithium, lithium intercalated graphitic carbons (LiXC) are being investigated and show high potential for good performance while retaining cell safety.

During discharge, lithium ions ( $\text{Li}^+$ ) are released from the anode and travel through an organic electrolyte toward the cathode. Organic electrolytes (i.e., nonaqueous) that are stable against reduction by lithium and oxidation at the cathode are required since lithium would react chemically with the water of aqueous electrolytes. When the lithium ions reach the cathode, they are incorporated into the cathode material quickly. This process is easily reversible. Because of the quick reversibility of the lithium ions, compared to lead acid or NMH technology, lithium-ion batteries can charge and discharge faster. Lithium-ion batteries produce about the same amount of energy as nickel metal hydride cells, but they are typically 40 percent smaller and weigh half as much. This allows for twice as many batteries to be utilized thus doubling the amount of energy storage thus increasing the range of the vehicle.

There are various types of materials being evaluated for use in lithium-ion batteries. Generally, the anode material being looked at is various forms of carbon with focus on graphitic and hydrogen-containing carbon materials. There are three types of oxides of transition being evaluated for the cathode: cobalt, nickel, and manganese. Initial battery



*Lithium Ion Batteries are stored beneath the passenger compartment in a "T" pattern, note the orange cables identifying the high voltage cabling.*



*The Hitachi Lithium Ion battery has reached a breakthrough in battery technology with a power density of 4,500 W/kg or 1.7 times the output of other lithium ion batteries.*

development appears to be using cobalt oxide which is technically preferred to either nickel or manganese oxides. However, the cobalt oxide is the costliest of the three, with nickel substantially less, and manganese being the least expensive.

In the construction of lithium-ion batteries, where cobalt oxide cathodes are used, the cathode is manufactured from an aluminum foil with a cobalt-oxide coating. The anode is manufactured from a thin copper sheet coated with carbon materials. The sheets are layered with a plastic separator, then rolled up like a jellyroll and put inside a steel container that is filled with a liquid electrolyte containing lithium hexafluorophosphate. This battery has an open circuit voltage of roughly 4.1 volts at full charge.

In addition to their potential for high specific energy, lithium-ion batteries also have an outstanding potential for long life. Under normal operation, there are few structural changes of the anode and cathode by the intercalation and removal of the smaller lithium ion. Additionally, the high voltage and conventional design of lithium-ion batteries hold promise for low battery cost, especially when cobalt is replaced by manganese.

Overcharge of lithium-ion batteries as with NMH and lead acid batteries, must be carefully controlled to prevent damage to the battery in the form of electrode or electrolyte decomposition. Because the electrolyte in a lithium-ion battery is non-aqueous, the gassing issue associated with the dissolution of water has been eliminated. Development of advanced battery management systems are key to ensure the batteries operate safely during normal operation and in the event of vehicle accidents. As previously mentioned for NMH and lead acid batteries, charging systems must be capable of working with the battery management systems to ensure overcharging does not occur.

### Vehicle Identification

Electric vehicles produced in the mid nineties were required to have badging and insignia on the sides and rear of the vehicle identifying the vehicle as an electric vehicle or "E.V." Neighborhood vehicles most of which run on electricity are easily identifiable from other vehicles on the road today. The next generation of all electric vehicles will not only have a distinctive aerodynamic design but will also carry identifying badging and insignia.

### Vehicle Operation

The operation of an electric vehicle is analogous to an internal combustion vehicle. An "ignition" key or numeric keypad is used to power up the vehicle instrumentation panels and electronic control module.



*Neighborhood electric vehicles like the GEM e-4 and all electric ATV's like the Bad Boy Buggy pictured here, can reach speeds up to 30 miles an hour with a range of 30-35 miles on a single charge.*

A gearshift placed in “Drive” or “Reverse” engages the vehicle. When the brake pedal is released, the vehicle may “creep” similar to internal combustion vehicles. When the driver pushes on the accelerator pedal, a signal is sent to the electronic control module which in turn applies a current and voltage from the battery system to the motor that is proportional to how much the accelerator is depressed. The motor then applies torque to the wheels.



*The manufacturers of electric vehicles incorporate familiar controls to simulate driving an ICE vehicle.*

Because torque/power curves for electric motors are broader than for internal combustion engines, acceleration in electric vehicles can be quicker. When the accelerator pedal is released, many electric vehicles have a built-in drag feature that mimics the engine compression of an internal combustion vehicle. This drag feature gently slows the vehicle.

Electric vehicles are equipped with a regenerative braking system. When the brake pedal is depressed to slow the vehicle, or if the vehicle is allowed to coast, the electronic control module changes the motor to a generator. The kinetic energy of the moving vehicle is then converted back to electricity as the vehicle slows down. This creates a sensation similar to downshifting to slow down an internal combustion vehicle.



*Regenerative brakes capture the kinetic energy, that is usually lost in slowing down or stopping, back into electrical energy.*

An appealing quality of the electric vehicle is that they operate noiselessly. For the most part, the handling and operation of many electric vehicles are comparable in operation and safety to their internal combustion counterparts. Emergency response personnel may not be able to determine if the vehicle is on or off by sound alone. Personnel should inspect the instrument panel for information regarding vehicle status. The 12-volt battery must be in operation for the instrument panel indicators to appear, so it is best to check the vehicle status before disengaging the 12 volt battery.

The major components of the electric vehicle are; motor and electronic control module, battery and battery management system, charger, cabling system, braking system.



*Only the electronic control module is visible under the hood of the EV-1.*

The electric vehicle is propelled by an electric motor and an electronic control module. In an electric propulsion system, it is the electronic control module that regulates the amount of current and voltage that the electric motor receives. The controller takes a signal from the accelerator pedal in the vehicle, and controls the electric energy provided to the motor, causing the torque to turn the wheels.

The motor and motor control unit, are both high voltage components and should not be tampered with. Care should be exercised when working around the engine compartment of any electric vehicle. High voltage wiring can be identified by wires that are red or orange color. Most automobile manufacturers are also putting high voltage labels on high voltage components. Many familiar vehicle components are not present



in electric vehicles. You will not find an air filter, carburetor, distributor, or spark plugs. In emergency response, look for the physical differences of the vehicle for a positive identification.

It is important for optimal performance of any battery type that a battery management system to monitor the operating condition of the battery pack is installed. Many electric vehicles incorporate battery management systems that are capable of monitoring the performance of each cell within the battery modules. Parameters such as cell voltage, current, and temperature are monitored to closely control the charge/discharge cycles, as well as temperature to preserve cycle life of the battery.

Electric vehicles have two different wiring systems: high and low voltage. The high voltage system is primarily for providing energy to the motor to propel the vehicle. However, some vehicle manufacturers have used high voltages to power heating/cooling systems, power steering pumps, and some sensors. The Society of Automotive Engineers (SAE), have developed a standard color code (red or orange) for high voltage wiring in electric vehicles.



Orange colored cabling identifies, for emergency responders, the high voltage cables running beneath the vehicle undercarriage.

A separate 12-volt auxiliary battery is typically used for accessories such as instrumentation, lights, stereo, etc. The separate 12 volt battery is kept charged by a DC to DC converter that “steps down” the voltage from the high voltage traction batteries.

In their electric vehicles, major automobile manufacturers use isolated electric busses for both the positive and negative sides of the battery. This is an important safety feature. In the event the positive electric bus loses isolation from the vehicle frame or chassis, no electrical current will pass through the frame or the chassis. The implication of this design feature is that vehicle drivers or emergency responders will not be shocked by the accidental loss of isolation between the positive or negative electric busses and the vehicle frame or chassis. This differs from internal combustion electrical systems because the 12 volt DC systems rely on the vehicle frame and chassis as the negative electric bus. However this is acceptable because 12 volt systems are not dealing with lethal voltages as is the case with the high voltage systems of electric vehicles.

All of the manufactured electric vehicles have special manual disconnects that uncouple the high voltage wiring system from the battery

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*Major manufacturers employ a variety of safety features to isolate the high voltage system from the rest of the vehicle including: pilot circuits, inertia switches, and manual disconnects,*

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pack. The location of these disconnects are vehicle specific and are intended to be used by service personnel doing maintenance on the vehicles. All of the production vehicles also have an automatic high voltage system disconnect as a primary safety feature. These disconnects are based either on ground fault monitoring, an inertia switch or a pilot circuit.

In the case of the ground fault monitoring disconnects, they operate on the same concept as the ground fault monitoring devices used in households. These devices monitor the ground system in the vehicle for current that may leak from the high voltage system. If a fault in terms of current leakage is detected, the devices automatically disconnect the high voltage system from the battery system. The location of the ground fault monitoring system is vehicle specific, but is typically found in the vicinity of the battery pack.

In the case of vehicles that use the inertia switch disconnect, the end result is the same but the method is slightly different. The inertia switch senses high deceleration rates, as may be encountered in a vehicle accident. If a rapid deceleration occurs, the inertia switch is automatically tripped and the high voltage system is disconnected from the battery system. The inertia switch is set for a low impact. Inertia switches are also common to internal combustion engines to deenergize electric fuel pumps in the event of an accident. In most cases, the inertia switch on electric vehicles can be reset by pressing the button on the device itself. Though, the location of these switches may vary from among vehicle designs, many are located in the motor compartment.



*The Pininfarina Electric Vehicle is a collaboration between French and Italian auto manufacturers. Note that the battery pack is installed under the passenger compartment.*

Other vehicles use pilot circuit disconnects, again the end result is the same but the method is entirely different. Throughout the motor compartment, high voltage cables are routed between the battery pack, electronic control module, motor, charging port, and other high voltage components. Running parallel to these high voltage cables is a pilot circuit that acts as a simple continuity loop. The pilot circuit is attached to the high voltage cable so that it is impossible to disconnect, sever, or rupture the high voltage cable without doing the same to the pilot. If an accident occurs resulting in the high voltage cable becoming disconnected, and hence the pilot cable, the pilot circuit will record that electrical continuity has been lost and automatically disconnect the high voltage cabling from the battery pack. The location of the pilot circuit disconnect system is also vehicle specific, but is typically found in the vicinity of the battery pack.

Some vehicle manufacturers are employing a combination of two disconnect systems for both redundancy and safety. Whether a ground monitor, inertia switch, or pilot circuit is used, it is important to know that these devices only isolate the rest of the vehicle from the

batteries voltage. Lethal levels of electricity may still be present in the battery pack. An electric vehicle battery pack should be treated with the same caution and respect as a fuel tank or cylinder found in internal combustion vehicles.

## EV Recharging

With electric vehicles comes electric vehicle recharging infrastructure, both public and private. The infrastructure includes recharging units, ventilation, and electrical safety features for indoor and outdoor charging stations. To ensure the equipment is installed safely, changes have been made to Building and Electrical Codes.

During electric recharging, the charger transforms utility-supplied electricity into energy that is compatible with the electric vehicle's battery pack. According to a definition by the Society of Automotive Engineers (SAE), the full "electric vehicle charging system" consists of the equipment required to condition and transfer energy from the constant frequency, constant voltage supply network to the direct current, for the purpose of charging the battery and/or operating vehicle electrical systems while connected (e.g., vehicle interior pre-conditioning, battery thermal management, on-board vehicle computer, etc.). The charger communicates with the battery management system which dictates how much voltage and current is delivered from the building wiring system to the battery system.

Charging is accomplished by passing an electrical current through the battery to reform its active materials to their high-energy charge state. The charging process is basically a reverse of the discharging process, in that current is forced to flow back through the battery, driving the chemical reaction in the opposite direction. The methodology by which this is done is different for each battery type due to the variations in chemical components.

The electric vehicle will be connected to some type of "Electric Vehicle Supply Equipment (EVSE)" that is, in turn, connected to the building wiring. This equipment is defined by the National Electrical Code (NEC) as "the conductors, including the ungrounded, grounded, and equipment grounding conductors, the electric vehicle connectors, attachment plugs, and all other fittings, devices, power outlets, or apparatuses



*This photovoltaic enhanced recharging station creates electricity to assist in recharging these early electric vehicle models. Electric vehicle charging stations were established in the mid-1990's in major metropolitan parking areas; airports, shopping malls, along with government and fleet facilities*

installed specifically for the purpose of delivering energy from the premise wiring to the electric vehicle.”

For residential and most public charging locations, there are two power levels that will be used. “Level 1”, or convenience charging would take place while connected to a 120-volt, 15-amp branch circuit and would result in a complete recharging cycle taking anywhere from 10-15 hours. This type of charging system uses the common grounded electrical outlets and would most often be used when Level 2 charging is unavailable. “Level 2” charging will take place while connected to a 240-volt, 40-amp circuit, dedicated for usage only by an electric vehicle. At this voltage and current level, a full recharge is typically 3 to 6 hours, depending on battery type. EVSE for this power level is required to be hard-wired to the premises wiring.

“Level 3” is any EVSE with a power rating larger than “Level 2”. The majority of the “charging system” is moved off of the vehicle platform. This type of charging would be the electric vehicle equivalent of a commercial gasoline service station where an electric vehicle can be charged in a matter of a few minutes. To accomplish this goal, it is probable that this equipment may be rated at power levels between 75-150 kilowatts, necessitating that the supply circuit to the equipment be rated at 480-volt, 3-phase, and between 90 and 250 amps. Supply circuits may even be larger. This Level 3 equipment would only be handled by specially trained personnel.

All EVSE equipment, at all power levels, will be required to be manufactured and installed in accordance with published standards documents such as: NFPA (NEC Article 625), SAE (J-1772, J-1773, J-2293, others), UL (2202, 2231, 2251, others), IEEE/IEC, FCC (Title 47 - Part 15), and several others.

There are currently two prime methods of transferring power to the electric vehicle; conductive and inductive. The connection process must be safe and convenient to use by everyone.



*The EV-1 used the inductive charging method, transferring energy magnetically to the vehicle battery pack.*

With the conductive coupling method, connectors use a physical metallic contact to pass electrical energy when joined together. Specific electric vehicle coupling systems (connectors paired with inlets) have been designed that provide a non-energized interface to the charger operator. Not only is voltage prevented from being present before the connection is completed, but the metallic contacts are completely covered and inaccessible to the operator.

The inductive connection is developed primarily for electric vehicle application (though it has seen some application with other small appliances). With this system, the coupling system acts as a transformer. Alternating current power is transferred magnetically or “induced,”



between a primary winding (on the supply side) to a secondary winding (on the vehicle side). This system uses EVSE that converts standard power-line frequency (60 Hz) to high frequency (80,000 - 300,000 Hz) reducing the size of the transformer equipment.

To ensure safe charging equipment to support electric vehicles, the National Electric Vehicle Infrastructure Working Council (IWC) was formed to address electric vehicle infrastructure. The IWC is a consortium of representatives from across the nation and around the world, representing industries such as electric utilities, automotive engineers, electrical manufacturers, code consultants, electric vehicle industry organizations, regulatory agencies, and independent testing laboratories such as Underwriters Laboratory.

The IWC developed recommended code language that address the electrical requirements for electric vehicle charging equipment and, along with the Society of Automotive Engineers (SAE), submitted code language proposals for inclusion in the 1996 National Electrical Code (NEC). After minor revision, the National Fire Protection Agency adopted Article 625, Electric Vehicle Charging System Equipment into the (NEC) which addresses electric vehicle charging equipment and systems. The IWC has also proposed codes for the Uniform Building Code. These codes cover issues associated with the location of charging equipment and the installation of ventilation systems when appropriate. While the electrical codes have been adopted nationally, the building codes have not. In California a modified version of both codes have been adopted and took effect August 19, 1996.

There are several issues associated with electric vehicle charging equipment that these codes address. Primarily, the issues can be classified as pertaining to electrical safety devices required in the equipment or ventilation of the location where the charging system is installed.

Regarding electrical safety for example, the electric vehicle connector must be polarized and be configured so that it is non-interchangeable with other electrical devices such as electric dryers. The method by which the electric vehicle charging equipment couples to the electric vehicle can be either conductive or inductive, but must be designed so as to prevent against unintentional disconnection. Additionally, the new electrical codes require that electric vehicle charging loads be considered continuous and therefore the premise wiring for the electric vehicle charging equipment must be rated at 125 percent of the maximum load of the charging equipment.

All electric vehicles charging equipment must have ground-fault circuit interrupter devices for personnel protection and rain-proofing for outdoor compatible equipment. An interlock to de-energize the equipment in the event of connector or cable damage must be incorporated.



*Check the currently adopted code in your jurisdiction for specific recharging system requirements.*

Furthermore, a connection interlock is required to ensure there is a non-energized interface between the electric vehicle charging equipment and the electric vehicle until the connector has been fastened to the electric vehicle. A ventilation interlock is also required in the electric vehicle charging equipment.

The ventilation interlock enables the electric vehicle charging equipment to determine if a vehicle requires ventilation and whether ventilation is available. If ventilation is included in the system, the ventilation interlock will allow any vehicle to charge. However, if ventilation is not included in the system, the mechanical ventilation interlock will allow non-gassing battery equipped vehicles to charge, but not gassing battery equipped vehicles.



*Buses parked in enclosed areas for maintenance or service should have adequate ventilation per code.*

Title 24, California Code of regulations addresses location and ventilation issues associated with electric vehicle charging. Specifically, these codes address where electric vehicle charging equipment can be installed. If a ventilated charging system is to be installed, the codes specify how much mechanical ventilation must be provided to ensure any hydrogen off gassed during charging is maintained at a safe level in the charging area.

The ventilation rates called out in the building codes are calculated to comply with the requirements of the National Fire Protection Association published in standard NFPA 69, Explosion Prevention Systems. This standard establishes requirements to ensure safety with flammable mixtures. Section 3-3, Design and Operating Requirements, requires that combustible gas concentrations be restricted to 25 percent of the Lower Flammability Limits.

This design criteria provides a safety margin when working with atmospheres containing hydrogen. Hydrogen is combustible in air at levels as low as 4 percent by volume of air. Therefore, for the charging station to not be classified as ‘hazardous,’ the hydrogen concentration must not exceed 10,000 parts per million, which equates to 1 percent hydrogen by volume of air.

### **Electric Vehicle Emergency Response**

Electric vehicles are safe to operate around under normal operating conditions. When involved in a collision, the redundant safety features of the vehicle are designed to protect the vehicle occupants as well as the emergency responders from electric shock.

When an electric vehicle is involved in an accident the inertia switch will automatically disconnect the traction batteries from the rest of the vehicle. If the vehicle is severely damaged, to the point where high voltage components and wiring have been severed, the pilot circuit

disconnect will also isolate the power to the traction batteries rendering the vehicle safe for emergency responders to work around.

Emergency responders should still approach the damaged vehicle as if it could pose an electrical shock hazard by wearing full protective clothing boots, and gloves.

### Electrical Safety

- ❖ Under no circumstance should the battery pack be cut into! While high voltage systems may be disconnected from the battery pack, the batteries themselves still have potential as an electric shock hazard.
- ❖ Emergency response personnel should avoid wearing; rings, necklaces, watches or any other jewelry when operating around an electric vehicle.
- ❖ Additional safety gear should be used including high voltage rated nonconductive boots and gloves for hands on personnel coming into physical contact with the vehicle.
- ❖ All hand tools, such as screw drivers, pry bars, and pliers, should be equipped with insulated handles rated for 1,000 volts.
- ❖ Do not cut high voltage wiring due to the potential for electric shock. High voltage cables and components can be identified by orange coloring or labeling.
- ❖ Manual disconnects are typically located at a point that is readily accessible to emergency response personnel to disconnect the battery pack from the rest of the vehicle.
- ❖ Do not cut through the high voltage wiring from the charging unit to the vehicle or the premise wiring. Power can be disconnected by removing the EVSE coupler from the vehicle, or turning off the power at the charging unit, the sub-panel or the buildings main electrical panel.

Other considerations when working with electric vehicles include battery location and weight. It is important to note the location and shape of the battery pack for all vehicles. Typically, the battery case is under the vehicle and/or between the vehicle's rear wheels. The battery case should not be opened, punctured, or cut into under any circumstance by emergency response personnel. If the battery is punctured by a conductive object, assume the object has electrical potential.

The weight of the battery pack especially in busses and transit vehicles maybe another consideration for the rescue and recovery of accident victims. The collective weight of the batteries can range between; 1,600 pounds for step vans, 5,000 pounds for busses, and in passenger vehicles from 1,000 to 1,500 pounds.



*Though redundant safety features should disconnect the high voltage system, emergency responders should always approach an electric vehicle as if it presents an electrical shock hazard.*



*When involved in a front end collision, this state owned electric car performed as it was designed to shut-down the high voltage system on impact.*



*Note the size and consider the weight of the batteries on an electric bus.*



*Buses and mass transit vehicles present the potential for mass casualties along with the need to mitigate the fuel/energy source.*



*As a rule lead acid batteries do not burn, if exposed to fire however the fumes and gasses are considered extremely corrosive.*

The curb weight of electric vehicles is essentially the same as their internal combustion counterparts. The weight of heavier engines and fuel tanks is replaced by the weight of the battery pack. Because the batteries are located low and in the center of the vehicle such as in transit buses, vehicle rollover should be rare. If a rollover should occur, the vehicle may need shoring up to keep the weight of the battery pack from potentially crushing the passenger compartment or shifting during rescue efforts.

## Electric Vehicle Fires

Vehicle fires that involve the interior of contents of the vehicle, and have not reached the battery storage area, can be safely extinguished with water. Vehicles in a structure that is involved in a fire can also be safely extinguished with water once the electrical utilities have been disconnected. Protecting the vehicle from additional fire damage would keep the fire from extending to the battery pack.

As a rule batteries do not burn, or rather, they burn with great difficulty. If batteries are exposed to fire, however, the fumes and gasses generated are considered extremely corrosive. Spilled electrolyte could react and produce toxic fumes and release flammable and explosive gasses when it comes in contact with other metals.

Due to the potential of explosive gasses, personnel should prevent and/or eliminate all open flames and avoid creating sparks. The population imbalance between electric and internal combustion vehicles is rather large and would suggest that should an electric vehicle become involved in an accident it would more than likely occur with an internal combustion vehicle. Circumstances should dictate whether or not the vehicles can be safely separated from one another to reduce the presence of fuel vapors in the vicinity of electrical sparks. Always assume that toxic and explosive gasses are present at the scene of the emergency.

## Lead Acid Batteries

With lead acid battery fires personnel should wear full protective clothing and self-contained breathing apparatus on positive pressure. Extinguish lead acid battery fires with CO<sub>2</sub>, Foam, or Dry Chemical. If batteries are on the charger, turn off electric power at the building supply source. Do not use water to extinguish due to potential shock hazard.

For a number of reasons, flooded lead acid batteries may still be used in mass transit vehicles such as school, tour, and municipal busses. In the case of an electric transit vehicle turnover, electrolyte could spill out in sufficient quantities to necessitate a hazardous materials response and cleanup. Passenger vehicles on the other hand, will more than likely use advanced sealed lead acid batteries, where the potential for leakage is



minimal. Advanced lead-acid batteries can be crushed to 60 percent of their original volume before any electrolyte is spilled. Should this occur, you may expect to see about a cup of electrolyte on the ground. The potential for a hazardous materials response for all passenger vehicle battery types, only occur in catastrophic accidents such as an electric vehicle being hit by a train where the hazardous material is spread out over a large area.

Cleanup for released or spilled Sulfuric Acid includes; removing all combustible Material and sources of ignition, and stop the flow of material (use duct tape over cracks in the battery case) and contain spill by diking with soda ash (Sodium Carbonate) or quick-lime (Calcium Oxide). Small electrolyte leaks can be flushed with water and neutralized with dilute acid (vinegar). Large spills must be contained, do not allow material to flow into storm drains.

### **Nickel Metal Hydride**

Extinguish Nickel Metal Hydride battery fires with Class D extinguisher (Metal-X or similar). If batteries are on the charger, turn off electric power at the building supply source. Electrolyte solution is extremely corrosive to all human tissue and reacts violently with many organic chemicals, especially nitro-carbons and chloro-carbons. The electrolyte also reacts with zinc, aluminum, tin, and other active ingredients releasing flammable hydrogen gas.

### **Lithium Ion**

Do not use water or foam to extinguish lithium-ion fires. Extinguish lithium-ion battery fires with dry sand, sodium chloride powder, graphite powder, or copper powder. Cleanup lithium-ion electrolyte spills with dry sand or other noncombustible material and place into container for disposal.

Fires involving both a structure and an electric vehicle can be extinguished using water and/or foam. The electrical power should be disconnected. If it appears that the fire has extended to the battery pack, extinguish with appropriate agent according to battery type.

To stay current on electric vehicle technology, it is recommended that you visit the “Electric Drive Transportation Association” web-site for new or updated information on this fuel technology. <http://www.electricdrive.org>. It is highly recommended that you go to the original equipment manufacturer for specific emergency response guidelines for specific makes and models of vehicles.

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*Nickel Metal Hydride  
Battery modules burn  
rapidly and can be  
quickly reduced to  
ashes leaving only the  
metal alloy plates.*

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*Hybrid technology is showing-up in a wide range of vehicles including this Foss Hybrid Tug Boat now being tested in the Long Beach Harbor.*

## C. HYBRID ELECTRIC VEHICLES

The first generation of the all electric vehicles in the mid 1990's provided several proven technologies that are now employed in Hybrid vehicles. The high-voltage system that was pioneered in all electric vehicles such as the motor and electronic control module, battery and battery management system, charger, cabling system, and regenerative braking system are all included in hybrid electric vehicles. Hybrid electric vehicles (HEV's) are vehicles that combine a small fuel efficient internal combustion engine with an electric power train.

Hybrid technology is not limited to passenger vehicles. The Port of Long Beach is experimenting with a hybrid tug boat. Mass transit vehicles also employ hybrid technology, so much so that mass transit hybrids will be treated as a separate module.

Then there are vehicles like the soon to be released Chevy Volt that are not technically hybrids. By definition a hybrid is a vehicle that uses two fuel/energy systems to directly power the drive train. The Chevy Volt is an all electric vehicle, that also uses an internal combustion engine, not to power the drive train, but to generate electricity for the electric drive train. The Volt, with both an internal combustion engine and electric motor on board, should also be included in this discussion for hybrid vehicles.

Honda and Toyota are the first auto manufacturers to offer hybrid electric vehicles to the general public. Other auto manufacturers are also offering hybrid vehicle options. Similar to all-electric vehicles previously described, emergency response to hybrid electric vehicles should follow the same basic safety protocols and precautions.

### Electrical Power

HEV's can take advantage of existing vehicle infrastructure and services. The HEV battery pack is recharged while the vehicle is moving-- eliminating the need for external recharging. However, there is a



*General Motors has embraced Hybrid Electric technology and now offers this as an option in a wide range of vehicle models*

strong movement for Plug-In Hybrids or PHEV's. Plug-in hybrid electric vehicles will have an additional battery pack to increase mileage and range of the vehicle. At this point plug-in hybrids are an after market addition to the hybrid vehicle, although manufacturers are researching the addition of plug-in options.

The size of the nickel metal hydride battery pack varies according to vehicle manufacture. The Toyota's, Prius, contains a 288 volt battery pack, while Honda's, Insight, contains a 144 volt battery pack.

Photovoltaic or solar generated electricity is also being experimented with. While solar powered cars are not a practical application today, due to the lack of surface area needed to generate enough electricity to power the vehicle, CNN news reports that Toyota is considering adding a photovoltaic module to the roof of the Toyota Prius to generate enough electricity to power the air conditioning system. One after market manufacturer has developed a Photovoltaic module designed to fit specific models of hybrid vehicles and claims that the module can add 20 to 30 extra miles to the vehicle. This will be an added consideration for emergency responders in the near future.

Emergency responders should always assume that high voltage components; cables, electronic control module, battery management system and motor, are energized when operating around the vehicle. A high voltage cable will run underneath the vehicle from the power supply in the rear of the vehicle to the electric motor under the hood. For quick identification, all high voltages cables will be orange. A 12-volt auxiliary battery provides service to the interior lights, radio, and air conditioner.

## Fuel Tank

The Honda's Insight utilizes a 10.6 gallon plastic resin gas tank instead of steel to help reduce the vehicles overall weight. The gas tank in Toyota's Prius, uses a collapsible internal bladder to reduce fuel vapors. In both vehicles the tank is located in the rear of the vehicle and under the battery pack. Hybrid vehicles currently use regular gasoline to power the internal combustion engine. Fleet vehicles may use other fuel types.

## Vehicle Identification

Auto manufacturers provide insignia, badges, or logos on the exterior to distinguish the HEV from other vehicle types. High voltage warning labels will be found around high voltage components in the engine compartment.

On the interior, the instrument panel is the most distinguishing characteristic of the HEV. The instrument panel will contain information regarding vehicle operation in digital and/or analog displays for fuel levels and the energy levels in the battery pack.



*After market installation of solar panels on the Toyota Prius could potentially increase vehicle range 20 to 30 miles.*



*Toyota Future Solar*



*The Pininfarina utilizes solar electricity to recharge the battery and extend vehicles mileage.*



*The anatomy of a hybrid electric vehicle includes an electric motor and gas fueled engine with a battery pack to store electrical energy. All Hybrid electric vehicles have badging and insignia identifying it as a hybrid electric vehicle.*



*An after market battery pack added to the Toyota Prius shorted and caused this electrical fire.*



### Vehicle Operation

Similar to internal combustion and all electric vehicle operation, the HEV driver will turn an ignition key to power-up the vehicle. Some vehicles manufacturers use a smart key system in which a power button replaces the ignition key. When the vehicles ready light is "on" and the shift selector is placed in "drive" the vehicle engages either/or both the internal combustion engine and the electric motor.

In Honda's Insight and the Toyota's Prius, pushing on the accelerator pedal the internal combustion engine and the electric motor will assist one another until the vehicle is at cruise speed. The electric motor or internal combustion engine will engage once again if the vehicle is under a load as in acceleration or driving up an incline.

In both vehicles, while coasting or braking, the electric motor reverses and becomes an electric generator which recharges the battery pack. When idling the engine and motor will temporarily shut-down allowing for additional fuel/energy savings. When the engine is off, the vehicle operates silently.

HEV's are made from essentially the same materials as other automobiles on the road. Small high performance engines made from light weight materials also help reduce vehicle weight. You will find light weight magnesium oil pans and a plastic gas tanks instead of steel constructed components. The HEV battery pack and electronic control module is smaller and more compact than their all-electric counterparts.

### Hybrid Vehicle Emergency Response

Firefighters should follow their department standard operating guidelines, many of which have been developed with the standards recommended in NFPA and IFSTA. Water is the recommended extinguishing agent and the attack line selected should be placed between any exposures and be from the uphill, upwind, and up-scene direction whenever possible. The attack line selected is recommended to be 1.5 inch or



greater. Approach to the vehicle should be at a 45 degree angle to avoid explosions from tires, and other hydraulic devices in the vehicle.

Engine compartment fires should be approached from a safe direction and generally require the hood to be opened or displaced to knockdown and extinguish the fire. The gas-electric hybrid vehicle will contain both an electric and gasoline motor, with various other engine components that are found on a standard vehicle.

Passenger compartment fires should be approached from a safe direction and may be extinguished with a properly selected fire stream that provides protection to the firefighter and will provide the required cooling and extinguishing effect. Standard and hybrid vehicles may now have one or more 12 volt batteries within the passenger compartment, under the front and rear passenger seats.

Fires that involve the vehicle rear or trunk of a hybrid vehicle must be approached with greater caution due to Hybrid Battery pack or pressurized fuel cylinder location. Fires located here in the battery pack may be attacked from a safe distance to the rear of the vehicle. It then can be extinguished with a properly selected fire stream that provides reach and protection to the firefighter and will also provide the required cooling and extinguishing effect.

There are two methods of fire attack if there is a confirmed hybrid battery pack fire. Direct fire attack where the compartment may be flooded from a safe distance to extinguish the fire in the battery pack. This will cool the battery pack to where there will be no more fire involvement. Battery components that are under fire conditions will burn out rapidly leaving only metal alloy cell plates within the pack. Battery fires often reignite. The use of copious amounts of water maybe necessary to keep the battery fire in check. Indirect fire attack may be used when the battery compartment is involved and the fire is allowed to burn itself out. The hose team will need to protect direct exposures with hose streams.

All hybrid high voltage battery systems are designed with fuses that will trip and restrict any high voltage from being released into a fire stream and pose a threat to responders. There will be no energized vehicle body parts after a fire. If any exposure of high voltage cables or engine parts occurs after a fire, do not handle, cut, or pry. Treat all high voltage components as if they were charged or were to become reenergized.

## **D. HYBRID-ELECTRIC BUS TECHNOLOGY**

Like electric buses, hybrid-electric buses range in size from small 22-foot shuttles and medium size buses to full-size transit buses. Many of the same cities operating electric shuttles are also purchasing new



*Response to vehicle emergencies occur every day throughout California.*

*—photo courtesy of VenturaCounty F.D.*

*Fires that involve the vehicle rear or trunk of a hybrid vehicle must be approached with greater caution due to Hybrid Battery pack or pressurized fuel cylinder location.*



*Enova School Bus and Hybrid information system in the cab.*

hybrid-electric buses. Several hybrid transit bus demonstrations are underway in Southern California and other areas of the country.

The typical 22-foot hybrid-electric shuttle buses operate in many of the same settings as their pure electric counterparts but are able to handle longer routes due to their increased range. The full-size hybrid transit buses operate on the same duty cycle as conventional buses. Hybrid-electric buses differ from pure electric and internal combustion buses because they use a battery pack as well as a fuel tank, and have a conventional internal combustion engine or turbine in addition to an electric motor.

### Hybrid-Electric Bus Batteries

The battery packs on hybrid-electric buses are smaller and store less energy than those on pure electric buses because the buses do not rely solely on the batteries for motive power. Like pure electric buses, hybrid buses plug in to the utility grid. Although some models depend on the grid for regular charging, many, especially the large transit buses, plug in only to “equalize” batteries to preserve the battery chemistry. Each manufacturer recommends different charging regimens.

As with batteries on pure electric buses, do not attempt to cut into or open the battery pack. With an operating voltage range of 200-700 volts, batteries pose potential electric shock hazards. The battery packs on hybrid-electric buses vary in size and configuration. Batteries on the shuttle-size hybrids are located under the floor, along the sides of the bus, directly in front of the rear wheels. Instead of three or four battery boxes, however, a fuel tank replaces at least one set of batteries. The same design elements seen on pure electric shuttles such as exterior access doors and metal structures to separate the batteries and fuel tanks are designed into these buses.

The full-size hybrid buses typically store their batteries in two long, flat tubs on the vehicles’ roofs. Their dimensions are approximately 9 feet by 3 feet by 1 foot. The weight of these batteries varies by manufacturer, but a typical hybrid bus battery pack weighs an average 1,600-2,200 pounds.

As stated previously, batteries burn only with great difficulty. If batteries are exposed to fire, typically the plastic casing, cabling and other flammable materials will burn; the insides of the batteries rarely burn. If, however, a battery’s electrolyte is spilled and exposed to fire, fumes and gases can be extremely toxic. Spilled electrolyte can cause short-circuiting of batteries and electrical circuits. Likewise, spilled electrolyte can react with other materials and produce toxic fumes. In addition, the presence of liquid and gaseous fuels in hybrid buses presents potential complications in the event of a battery fire.

Almost all hybrid-electric shuttle buses currently on the road in the U.S. use lead-acid batteries. Some manufacturers are testing nickel-metal hydride and nickel-cadmium batteries. The previous discussion on electric bus and electric car technology discusses the properties of these batteries and appropriate emergency response.

## Liquid and Gaseous Fuels

Another challenge for emergency response personnel is to quickly identify the type of fuel being used on the hybrid vehicle and to assess the potential hazards. While full-size transit bus hybrid engines typically run on diesel, small shuttle-size hybrids with microturbines (and the full-size buses that are using larger microturbines) can operate on liquid or compressed natural gas, propane, or diesel fuel.

### Diesel

Most of the full-size transit hybrids use diesel fuel instead of CNG or LPG. For most emergency response agencies this is a familiar fuel and standard-operating guidelines apply to emergency response if the fuel is spilled or involved in a fire.

Diesel fuel is stored and transported as a liquid. The flammable limits for diesel are a low 0.6-7.5 percent and the auto-ignition temperature for diesel is 230°C. Comparatively, the auto-ignition temperature for CNG and LPG is 450°C and the auto-ignition temperature for gasoline is about 300°C. Similar to propane, diesel fumes are four to six times heavier than air and can pool in low-lying areas.

Diesel fuel leaks in the tank or fuel lines should be stopped using plugs and/or stoppers designed for this purpose. Prevent leaking diesel fuel from entering storm drains and other waterways. Clean up spilled diesel fuel with an absorbent material. Use foam to extinguish diesel fuel fires. As with all operations involving fuels and fires, use full structural fire-fighting gear and SCBA.

The fuel tank on hybrid shuttles usually occupies the space used by a battery compartment in a pure electric shuttle. Typically, it is put in place of the forward-most battery on the street side. The size of the tank varies depending on the fuel, but is typically, 50-75 gallons for diesel, propane or LNG fuel.

CNG tanks are typically smaller, and are mounted on the roof — the most common placement of CNG tanks in today's CNG-fueled transit buses. The diesel tank in the full-size transit hybrid typically is located under the curbside passenger seats.

The Natural Gas or Propane fuel cylinders on all hybrid buses must meet applicable standards for safety, strength, secure attachment, and

*Another challenge for emergency response personnel is to quickly identify the type of fuel being used on the hybrid vehicle and to assess the potential hazards.*

ventilation. For example, NFPA 52 and FMVSS 303 ensure that pressurized CNG fuel cylinders are shielded from damage by road hazards and mounted to minimize damage from a collision. To this end, fuel cylinders cannot be mounted before the front axle or after the rear axle. The cylinders must be securely fastened to the frame of the vehicle and shielded from direct heat generated by the vehicle's exhaust system. Pressure relief valves must be vented to the outside of the vehicle.

Manufacturers have designed their vehicles to ensure that no electrical sparks from high voltage systems come in contact with fuel tanks. Propane and LNG tanks used on the shuttle buses are approximately one-quarter inch thick steel and are separated from the battery compartments by structural members and sheet metal. The larger transit buses, with their fuel tanks underneath the floor and battery packs on the roof, have separation built in to their vehicle designs.

### Vehicle Identification

Like their electric bus counterparts, many, but not all, hybrid-electric buses display large lettering indicating that they are hybrids. Each fuel has its own industry-approved symbol. Most hybrid-electric bus manufacturers have incorporated the industry symbols for LPG, CNG or LNG, into their designs to aid emergency response personnel in identifying the type of fuel used on board. Although some buses do not prominently display their hybrid status, the fuel symbols will be present on the rear bumper and in the appropriate compartment, such as on the fuel tank compartment door or fuel-fill cover.

### Vehicle Operation

A hybrid-electric bus operates much like any other bus: the driver turns the key or pushes a button to start the vehicle and shifts a gear to begin movement. Acceleration is fast and smooth, as on an electric bus, but this is where the similarity ends. This section describes the different hybrid bus technologies.

The components on a hybrid-electric bus include: drive system, controller, electric motor, and turbine or conventional internal combustion engine; fuel storage, including battery and battery management system, and fuel tanks and piping; cabling and wiring; brakes; body and frame. All hybrid buses use regenerative braking systems.

As with electric cars and buses, you may not be able to immediately identify that a hybrid bus is "on" because it may be quiet. When some hybrid buses, such as the small shuttles, are stopped, the engines or turbines turn off so there is no engine rattle or vibration typical of a conventional bus. The engines on the full-size transit buses typically do not shut down when they are stopped. Check the vehicle's instrument panel



*There are many hybrid electric buses on the road today that use a range of fuels to power the internal combustion engine.*

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***The operating voltage  
for full-sized hybrid  
electric bus is between  
500 to 700 volts.***

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for indication lights to determine whether or not the bus is on. Even if the bus appears to be turned off, always assume high voltage is present due to the possibility of component or indicator failure.

Some large transit buses are designed to perform battery optimization after they are turned off, which means some components beside the batteries may still be energized with high voltage. In general, always assume high voltage is present between the batteries and associated cabling.

Many of the shuttle and medium-size hybrids can start their duty cycle in all-electric mode if the driver chooses. When the driver steps on the accelerator in a hybrid-electric shuttle, it sends an electrical signal to the controller/power converter unit, which controls the energy flow to the electric motor. The motor then drives the wheels. Electric motors in shuttles typically are AC induction, while motors in mid-size 35-foot hybrid buses are AC or DC directly driving the axle, depending on the configuration. After the batteries have been discharged to a predetermined level, the system's microturbine turns on automatically to recharge the batteries while the vehicle is operating. The controller directs current flow primarily from the batteries, but as power requirements dictate, supplements with current generated by the turbine.

Based on the same technology as a jet engine, a microturbine generates electricity through rotating components mounted on a single shaft and supported by air bearings. An axial compressor feeds high-pressure air to a combustion chamber where fuel is injected and burned, producing an exhaust stream that spins a turbine at up to 96,000 RPM. A permanent-magnet generator mounted on the shaft produces electric current, generating 30 kW. The microturbines in use with the small- and medium-size hybrid shuttles run on compressed or liquefied natural gas, diesel, or propane.

The operating voltage of a typical small or medium-sized hybrid-electric shuttle using a microturbine is 200-700 volts. Full-size hybrid-electric buses operate at 500-700 volts. Do not tamper with these high voltage systems. The electrical components are typically labeled "high voltage." You can identify high voltage cables by the color of their insulation: bright orange, red and white, or yellow. As with any internal combustion engine, do not expose yourself or others to an engine running in an enclosed space; asphyxiation or carbon monoxide poisoning can occur.

Some of the full-size transit buses have an onboard sensor that automatically shuts down the engine in the event of fire. Likewise, some of the hybrid shuttles feature an automatic sprinkler/fire suppression system that engages when heat sensors in the battery and microturbine compartments sense abnormally high temperatures. This system automatically shuts down the vehicle and all high-voltage systems and discharges chemical or foam fire suppressants into these compartments.



*The high voltage system on hybrid electric buses are the same as those that are on all electric buses.*

The high voltage system is located in the same place on hybrid buses as on pure electric shuttle buses — at the back of the vehicle. It is clearly marked “high voltage” inside the external door, and all high voltage cabling is insulated with a bright orange loom, the color recommended by the Society of Automotive Engineers (SAE), and isolated from low voltage wiring. In some buses, the insulation is red or yellow.

These buses have the same safety features to turn off the high voltage system as their electric counterparts. They are: ignition key or master switch, manual shutoff switch accessible from the driver’s seat, emergency cut-off switch located in the back of the bus with the high voltage components, inertia switch in some models, and automatic fire extinguishing systems in others.

On Full-Size Buses, the high voltage propulsion control system is typically located on the roof toward the back of the bus. The electric motor resides directly behind the rear wheels, and the generator is located behind the motor, accessible from the rear access door. As with other hybrid and electric buses, the areas are clearly labeled high voltage and all high voltage cabling is wrapped in red and white tape weave. Some manufacturers use orange or yellow tape.

A high voltage master disconnect switch is located in the vehicle battery compartment on the rear curb side of the bus. Other switches disconnect both 12-volt and 24-volt power isolator switches. All three switches should be turned off in the event of an accident or emergency. Remember, while the configuration varies by manufacturer, it is reasonable to assume that similar systems for disconnecting high voltage and low voltage exist on large hybrid transit buses.

Even with all of the safety precautions in place, there is still high voltage present in the batteries and associated cables. Do not cut high voltage wiring because of the potential for electrical shock. Use caution when working around or near the traction battery system. Remember that high voltage wiring is marked in orange.

### **Hybrid-Electric Bus Refueling/Recharging**

Electrical infrastructure requirements for hybrid buses are similar to those for electric buses, although the charging requirements for the different hybrid vehicle designs are quite different. While smaller shuttle buses typically charge every night as do their electric bus counterparts, the full-size transit buses charge less frequently – and then only for battery equalization, which is a routine maintenance requirement.

The charging process, use of conductive couplers and Level 2 and 3 charging, basic design recommendations such as distance between the bus and the charger, and temperature control are comparable for electric and hybrid-electric buses.

Building codes dictate where electric vehicle charging equipment can be installed. As with electric cars, ventilation in areas where electric buses are charged must comply with requirements in NFPA Standard NFPA 69, Explosion Prevention Systems. Article 625 of the National Electrical Code (NEC®) also addresses ventilation requirements for enclosed spaces used for EV charging.

Refueling facilities for the various liquid and gaseous fuels used in hybrid buses must follow all applicable standards for the fuels used. Operators must take care to ensure that high voltage charging, for example, does not occur in close proximity to CNG refueling. Typically, separate buildings and refueling stations exist to ensure separate infrastructures.

The Standard for CNG Fuel Systems, NFPA 52, ensures that refueling stations have manual shut-off valves. One shut-off valve is located at the tank. An emergency shut-off valve, which terminates the power supply and gas supply to the compressor and dispenser, is located at a distance from the refueling area.

Breakaway protection is also provided in the event of a vehicle pulling away from the refueling station while the hose is still connected to the vehicle. The breakaway device stops the flow of natural gas.

Emergency response to refueling stations must include the use of full structural firefighting clothing and SCBAs. Preplans of the facility should include the location of fuel tanks and manual shut-off valves. If a vehicle is on fire at the refueling location, manually shut down the refueling operation at the tank or from the remote location. Disconnecting the main power source to the facility will also shut down the flow of fuel. You can then put out the fire using water and foam. If the tanks are involved in a fire, approach the tanks from the side and use water to cool the tanks and other exposures.

### Hybrid Bus Emergency Response

Emergency response to fires in hybrid buses depends upon the different fuels in use. Generally speaking, the use of water and foam will mitigate a majority of incidents. Even if no fire is present, responders should deploy hose lines to protect exposures (nearby property) and passengers exiting the bus in the form of a rescue path.

Remember, as with pure electric buses, the first priority after passenger evacuation is eliminating the potential for fire on the bus to spread to the batteries or fuel compartments. It is good policy to separate internal combustion vehicles from electric and hybrid electric buses to minimize gasoline fuel vapors in the vicinity of electrical sparks. Use water or foam to extinguish flames. Follow standard fire response procedures for each fuel and battery type.

*If a vehicle is on fire at the refueling location, manually shut down the refueling operation at the tank or from the remote location.*



*Bus fires occur fairly regularly. Response personnel should preplan for this type of emergency.*

When performing extrication, avoid cutting in the high voltage areas around the batteries, the high voltage components or cabling. In addition, do not cut fuel lines; escaping liquid or gaseous fuels may have flammable or explosive properties upon release into the atmosphere.

Extinguish hybrid-electric bus fires with water or foam. Remember that the basic body and shell of the bus contains the same materials as any other bus. These materials can be toxic if fully engulfed in flames. Use full structural firefighting gear and SCBA.

Do not cut through the high voltage charging wire extending from the bus's charge port to the charging unit. To disconnect the power, turn off the charging unit, turn off the sub-panel or flip the breaker in the building's main panel. After the power is off, you can safely disconnect the charging connector from the bus. Take note that there may be separate electrical meters and power supply boxes for the hybrid-electric buses and for the rest of the building.

In the event of a hybrid-electric bus fire during charging, first disconnect the power to the charger, either at the charger itself or at the building's circuit breaker as described above. Extinguish the fire using standard procedures, water and/or foam. If the fire has engulfed the battery pack, follow the procedures for that specific battery type. Similarly use appropriate extinguishing agent for the type of fuel on-board.

Emergency response to hybrid electric vehicle collisions and emergencies should follow the same protocols for all-electric vehicles. Emergency response personnel should:

- ❖ Wear full protective clothing when working around electric vehicles including turnout coats, pants, helmets, gloves, and boots.
- ❖ Avoid wearing rings, watches, or any other jewelry when working around any type of electric vehicle to guard against potential shock hazards.
- ❖ Use additional safety gear including; high voltage rated non-conductive boots & gloves.
- ❖ Use hand tools, such as screw-drivers, pry bars, and pliers equipped with insulated handles.
- ❖ Wear self-contained breathing apparatus in the vicinity of any and all vehicle fires.
- ❖ Avoid cutting or puncturing the battery pack or high voltage cables.

## **E. HYDROGEN FUEL CELL**

It was in the late 1800s when the first automobiles came on the scene. These early cars used a variety of fuels and engines, including steam



engines and electric motors. Over time, internal combustion engines using gasoline and diesel became most common and are the majority of the vehicles on the road today.

Automakers have always pursued other types of vehicles and fuels. Today, many of these vehicle technologies are gaining attention as the world looks for cleaner vehicles and non-petroleum fuels. Many automakers are exploring electric drive technology with gasoline-electric vehicles, all electric vehicles and fuel cell electric vehicles.

California has more fuel cell vehicles (FCVs) and hydrogen fuel stations than in any other region of the world. Average Californians drive and fuel many of these vehicles that are part of demonstration fleets at government and municipal agencies, parcel delivery companies, transit agencies, utility providers, universities and even as private vehicles.

As of January, 2007 the California Fuel Cell Partnership (CaFCP) members have placed 158 FCVs and nine buses on California's roads in demonstration programs. Many of these vehicles are on the road every day in the greater Los Angeles area, San Diego, Palm Springs, Sacramento, and the San Francisco Bay Area. The vehicles fuel at 23 regional hydrogen stations, with many more planned in the very near future.

Fuel cell vehicles on the road in California today incorporate extensive safety systems similar to and, in many cases, more advanced than those incorporated in conventional gasoline vehicles. In fact, many automobile and energy industry experts point out that FCVs have potential safety benefits over conventional vehicles.

The safe use and operation of FCVs is a priority for CaFCP members. Educating emergency responders about the unique characteristics of FCVs is vital to promote safety. "The Hydrogen Fuel Cell Vehicle Emergency Response Safety Handbook" reproduced in part here, covers the fundamentals of this promising technology and is intended to supplement established emergency response training materials.

An FCV, powered by an electric motor, provides an environmentally friendly solution for air quality, and has great acceleration and torque. Compared to conventional vehicles, FCVs offer:

- ❖ Zero tailpipe emissions – a hydrogen-powered fuel cell vehicle has no polluting exhaust. The only tailpipe emission is water vapor.
- ❖ Quiet operation – FCVs can reduce noise pollution in urban areas.
- ❖ Energy efficiency – Fuel cell vehicles are 2-3 times more efficient than conventional vehicles.
- ❖ Energy diversity – hydrogen can be obtained from many sources, including renewables presenting the opportunity to develop a more diverse and sustainable energy supply portfolio.



*Fuel Cell buses are seen in and around major metropolitan areas of the State.*



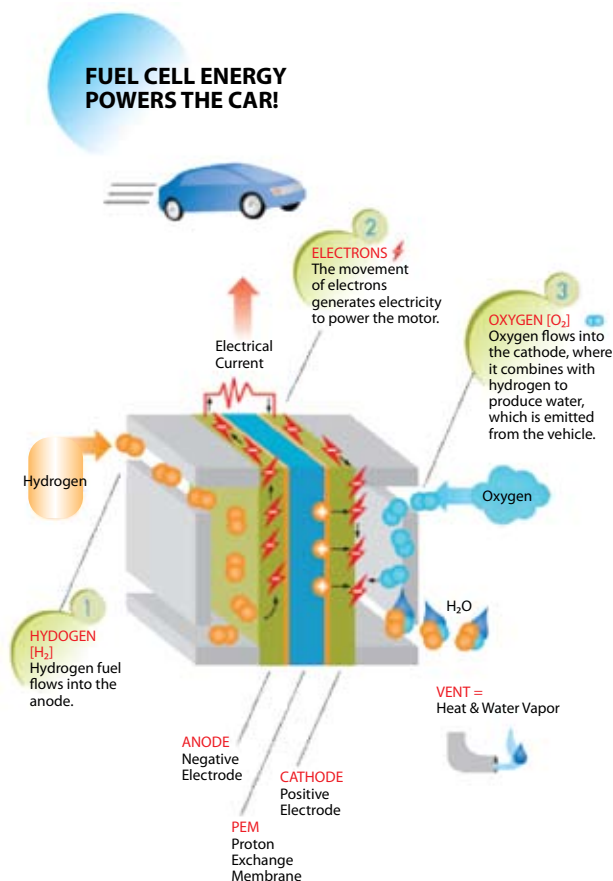
*This Nissan demonstration vehicle reveals the drive system underneath the passenger compartment.*

A fuel cell is an electrochemical device that produces electricity efficiently, silently and without combustion. Unlike a battery, a fuel cell does not require recharging. It will produce electricity as long as hydrogen fuel is supplied. Fuel cells have been a reliable power source for many years. Fuel cells are currently used to power vehicles, buildings, laptop computers and video cameras.

### Fuel Cell and Hydrogen Properties

Automakers use a type of fuel cell called a Proton Exchange Membrane, or PEM, fuel cell. The PEM fuel cell uses an electrochemical reaction between hydrogen and oxygen to generate electricity. Like a conventional battery, a PEM fuel cell consists of two electrodes, the anode and the cathode, separated by a polymer electrolyte membrane coated on either side by a catalyst.

Hydrogen flows into the anode, where in the presence of the catalyst, the hydrogen molecules dissociate into electrons and protons. The hydrogen protons are able to pass through the membrane into the cathode. The electrons flow through an external circuit which produces electricity to power the vehicle. The electrons rejoin the protons in the cathode, and combine with oxygen to form water and heat.



Individual fuel cells are combined into a fuel cell stack that resembles a loaf of bread. The number of fuel cells combined into a fuel cell stack determines the amount of power it can supply. Today's FCVs use between 65 and 90-kilowatt fuel cell systems. Many FCVs also use a high-voltage battery similar those in gasoline-electric hybrids to supplement the fuel cell and recover energy during braking.

In an FCV, hydrogen is stored in tanks on-board the vehicle as a compressed gas. A few vehicles, however, store the hydrogen as a liquid.

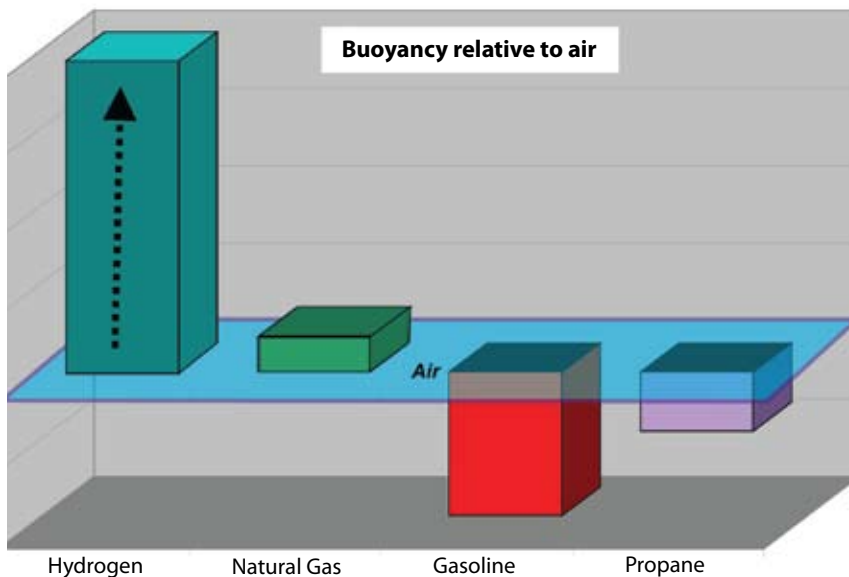
When handled properly, hydrogen is as safe as or safer than other fuels. Its properties are unique and must be well-understood to be handled appropriately. Unique properties, such as buoyancy and diffusivity, can often times make it more manageable than hydrocarbon fuels.

As discussed earlier in the internal combustion section, hydrogen is the simplest of all elements, containing one proton and one electron. In nature, it's never found by itself, but always combined with something else. You'll often see hydrogen referred to as " $H_2$ " to denote its molecular structure—always two atoms bound together. Hydrogen

has a very low boiling point (-423oF) and is predominantly used in its gaseous form in fuel cell vehicles.

Gaseous (GH<sub>2</sub>) hydrogen is the lightest of all gases. Because hydrogen's density is 0.07 times the density of air, it rises and diffuses rapidly. Compared to natural gas, GH<sub>2</sub> rises eight times faster and diffuses approximately four times more rapidly. Gaseous hydrogen is flammable, but does not "pool" on the ground like gasoline, diesel or propane fuel vapors.

Hydrogen gas is nontoxic, non-corrosive and benign to the environment. It can, however, rapidly fill a confined space and, like any gas that displaces oxygen, it can induce suffocation (asphyxiation). Asphyxiation warning signs and symptoms include dizziness, drowsiness, nausea and/or loss of consciousness. (Please see the hydrogen Material Safety Data Sheets (MSDS) or Sourcebook for Hydrogen Applications published by the US Department of Energy for additional information about health hazards.)



Hydrogen, like all fuels, is flammable. Because it is a small, active and light molecule, it can be more difficult to confine than other fuels. When hydrogen does ignite, it burns with an invisible or near-invisible flame. The graph and table on the next page relate the ignition energy required to ignite a fuel mixture at the upper and lower flammability limits (UFL and LFL, respectively) of hydrogen, gasoline, and methane (CH<sub>4</sub>).

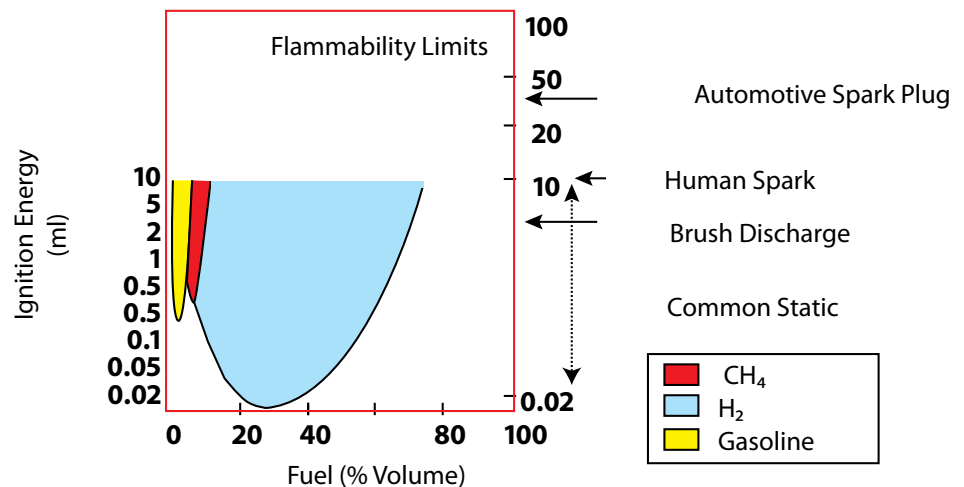
The ignition source must have enough energy to ignite the fuel (i.e., the energy level should be on or above the curve for each gas). A variety of ignition sources can ignite gasoline, natural gas and hydrogen-air

mixtures, sometimes as low as common static if it occurs in the proper mixture percentage.

Explosive hydrogen-air mixtures are difficult to create, requiring high hydrogen concentrations in air from 18.3% to 59%, conditions typically only possible in special, confined spaces. Furthermore, the concentration of fuel to air mixture for hydrogen is 29%, significantly greater than that of gasoline vapor or natural gas (2% and 9%, respectively).

The lower flammable limits (LFL) for hydrogen (4%) is higher than gasoline (1%). This means it requires a greater percentage of hydrogen in the air than gasoline to ignite. Hydrogen does, however, have a wider flammability range (up to 75% in air) than methane or gasoline. This wide range of flammability presents an increased probability of ignition. Hydrogen's dispersion characteristics tend to reduce the likelihood that a flammable mixture will form in air.

For hydrogen to exist as a liquid, it must be kept at cryogenic temperatures in pressurized and thermally insulated containers. The boiling point for hydrogen is -423°F (-253°C), and evaporation occurs in a 1:848



Flammability Limits of H<sub>2</sub> Are Seven  
Times Wider Than CH<sub>4</sub>

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Property	Hydrogen	Propane	Gasoline	Natural Gas
Ignition energy in MJ/g	20	250	250	300
Lower flammability limit in air at room temperature and one atmosphere	4%	2%	1%	5%
Upper flammability limit in air at room temperature and one atmosphere	75%	10%	8%	15%



expansion ratio (see Appendix A). Most of the liquid hydrogen used for FCVs is in storage containers at hydrogen fuel stations. Some vehicles, however, store LH2 rather than GH2.

Liquid hydrogen poses a frostbite hazard (cryogenic burns) if it comes in contact with skin. Additionally, in the case of emergency release, super-cooled components such as pressure release devices, pipes and valves, can “burn” the skin upon contact. Please refer to the MSDS Sheets and the DOT Emergency Response manual when dealing with liquid hydrogen.

Due to hydrogen’s extremely low boiling point (the lowest of any matter other than helium) and its high expansion ratio, LH2 storage tanks typically use a vent stack to safely release GH2 and prevent tank over-pressurization (see the Hydrogen Station Emergency Response Safety Handbook for more information on specific applications for LH2 storage).

A white cloud formed by condensed water vapor (and sometimes liquid oxygen) may indicate venting or leaking LH2. These clouds may—because of the higher density of cold gases—move horizontally or even downwards and contain cold GH2. The hydrogen cloud may extend beyond the visible portion of a vapor cloud. This hydrogen will, however, warm up within seconds and quickly disperse upwards.

The cryogenic temperature of released LH2 can liquefy ambient air, which can cause the same frostbite hazard as the LH2 itself. For this reason, LH2 storage tanks are typically installed on concrete pads. Liquefied air has a high oxygen content (up to 50%) that can react with surfaces containing tar and asphalt. The result can be an explosive mixture with low ignition energy.

In the case of an LH2 or GH2 release, eliminate ignition sources, including open flames, mechanical sparks, electrostatic discharges, sparks from electrical equipment, and welding and cutting operations. When building or permitting a station, make sure none of these ignition sources are near the hydrogen vent stack.

### Fuel Cell Vehicle Identification

In most cases FCV are built from existing makes and models of vehicles you see on the road every day. You can identify a fuel cell vehicle by:

- ❖ Vehicle graphics – Most fuel cell vehicles display graphics or lettering on various body panels indicating that the vehicles are powered by fuel cells.
- ❖ Blue diamond identification symbols – Usually applied to the rear of the vehicles, the blue diamond identifies the type of fuel stored in the fuel tank. The diamond is usually blue with white lettering.



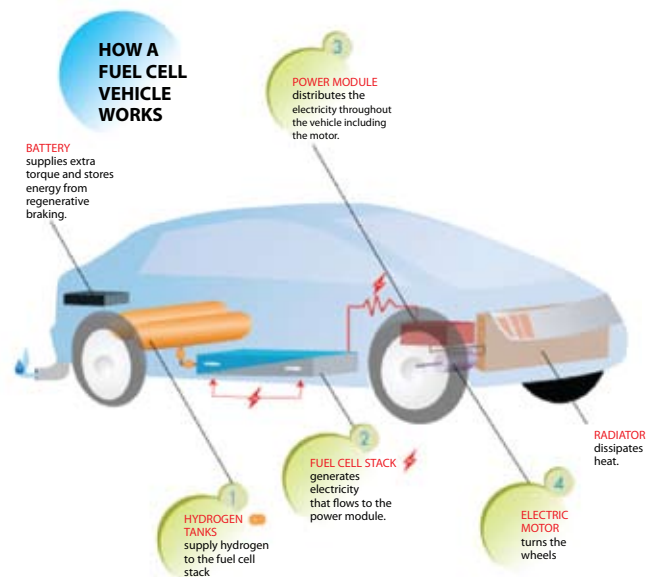
Compressed  
Hydrogen

Liquid  
Hydrogen

## Fuel Cell Vehicle Operation

Fuel cell vehicles are electric vehicles that use hydrogen stored in tanks on board and a fuel cell stack to create electricity instead of requiring a rechargeable battery. The electricity from the fuel cell stack flows into a power module, which distributes the electricity to the electric motor that turns the wheels of the car. In many models, a high-voltage battery, similar to those in gasoline hybrids, provides extra torque when accelerating or climbing a hill, and helps improve fuel economy. An FCV's components include low and high voltage systems, a fuel system and vehicle safety systems.

Most light duty fuel cell vehicles are built on existing vehicle platforms of each auto manufacturer and drives like its internal combustion counterpart. All fuel cell vehicles have the same basic components (electric motor, fuel cell stack, cooling system, etc.). Component placement



Since 2000, nine fuel cell buses have been placed into service in California by SunLine Transit in Thousand Palms, Alameda-Contra Costa Transit (AC Transit) in the San Francisco Bay area and Santa Clara Valley Transportation Authority (Santa Clara VTA) in the Silicon Valley.

varies somewhat in different makes and models, just like conventional vehicles. Light duty fuel cell vehicles are heavier than their conventional counterparts, (anywhere from 700 to 1,000 lbs.) primarily because of on-board hydrogen storage and the weight of the fuel cell stack.

Similarly, a fuel cell bus (FCB) drives much like its internal combustion engine counterpart. Because its fuel tanks are on the roof, a FCB is taller than a diesel bus, but about the same height as a CNG bus. The FCB is about 5,000 pounds heavier than a diesel bus and 2,200 pounds heavier than a compressed natural gas bus.

Fuel cell vehicles have both low voltage and high voltage electrical systems. The low voltage system is powered by a 12-volt battery similar to those found in conventional vehicles and runs the 12-volt accessories. As with conventional vehicles, disconnecting a 12-volt battery cable shuts down the vehicle and isolates sources of electrical energy. The high voltage system powers components that propel the vehicle.

The high voltage system includes the fuel cell, propulsion motor, high voltage cables and other power electronics components. Some vehicles also have a high voltage storage device (batteries or ultra capacitors). The high voltage systems in FCVs range from 200 to 450 volts. High voltage cables are orange, as SAE recommends (Figure 6). For specific information about the location of these cables, please refer to the ER FCV Diagram for each vehicle model or to manufacturer-issued documentation.

When a vehicle shuts down, the high voltage delivery system is designed to deactivate in seconds. Depending on the amount of hydrogen still in the fuel cell, it may take up to a few minutes for the electric motor and fuel cell stack to completely discharge. Only the high voltage batteries or ultra capacitors retain an electric charge after vehicle shut down.

Compressed gaseous hydrogen (GH<sub>2</sub>) is generally stored in Type 3 or Type 4 pressurized vessels or tanks (Figure 7). These tanks are stronger than conventional gasoline tanks and built to Canadian Standards Association (CSA) International standards. A Type 3 tank is an aluminum-lined tank with carbon fiber wrapped on the outside. The Type 4 tank has a polymer lining (typically polyethylene) with a carbon fiber wrap. The carbon fiber provides additional strength for these types of vessels.

The maximum pressure level used on a given vehicle type depends on the fuel tanks installed. Currently, storage tanks on the vehicles hold hydrogen at either 5,000 psi (350 Bar) or 10,000 psi (700 Bar) when completely full. The actual pressure depends on the amount of hydrogen in the tank and the allowable working pressure, which can be as low as a few hundred psi or as high as 10,000 psi. Vehicles and tanks are extensively tested and are designed to maintain their integrity in the event of an impact.

In the event of a fire impinging on the hydrogen storage tank, a temperature-activated pressure-release device (PRD/TRD) will open to rapidly release hydrogen, usually within a few minutes. The PRD/TRD is integrated into one end of the tank assembly and is sometimes routed through a vent stack. In vehicles with multiple tanks, each tank has its own PRD/TRD. If a PRD/TRD activates, you will usually hear a “bang” followed by a loud hissing sound, similar to the sound of a high pressure air hose. The tank will empty in 2-3 minutes.



*The elevated roof on the Ballard Hydrogen Bus stores the hydrogen cylinders that power the vehicles fuel cell.*

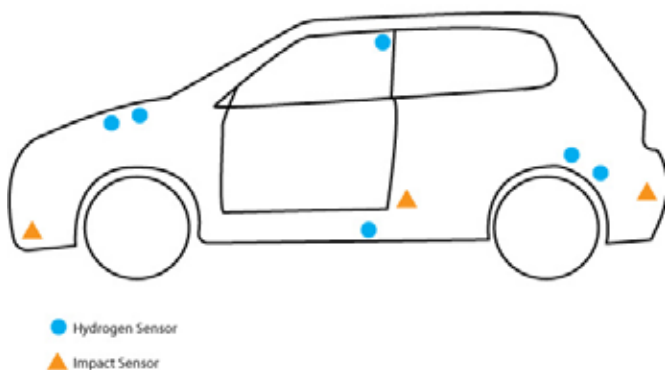


A controlled pressure release can ignite into a concentrated invisible or nearly invisible flame. Typically, particles in the air and/or combustible materials in the vent area will render a visible flame. Hydrogen flames radiate one-tenth the heat of gasoline flames, so the sensation of heat is not a strong indicator of a flame. (Other sections of this handbook cover this in more detail.)

A fuel cell system operates at a much lower pressure than the GH<sub>2</sub> storage tanks. High pressure hydrogen is generally regulated below 70 psi (5 Bar) just outside of the storage tanks, reducing the amount of high pressure piping. This lower pressure hydrogen is fed into the fuel cell through fuel lines. These lines are stainless steel tubes routed between the fuel tanks and fuel cell stack. Some FCVs have high and low pressure lines located in the vehicle.

When the vehicle is turned off, solenoids that default to a closed position securely isolate the high-pressure hydrogen inside the fuel tanks. A small amount of low-pressure hydrogen may remain in the fuel lines, but the equivalent in energy is no more than a tablespoon of gasoline.

Liquid hydrogen, stored cryogenically at -423°F (-253°C), is more common at hydrogen fuel stations than on board FCVs. Vehicle storage tanks for LH<sub>2</sub> are typically made of stainless steel and are stronger than gasoline tanks. Cryogenic LH<sub>2</sub> cylinders have a tank within a tank with a vacuum seal between the inner and outer tanks. This forms a thermos-like insulating protection to reduce the rate of boil-off of the cryogenic hydrogen. If not operated for a week or so, some models of LH<sub>2</sub> vehicles will safely vent hydrogen gas from time to time to prevent pressure build up in the cryogenic storage tanks.



*Diagram shows a sample of hydrogen sensors and impact sensors that will shut off hydrogen fuel supply if the vehicle is damaged.*

Ice frost or ice crystals on the outside of the fuel tank may indicate a leak or tank failure. If a serious accident caused the inner tank to fail, the pressure relief valve will expel excess GH<sub>2</sub> through a vent stack to the atmosphere.

### Vehicle Safety Systems

Pre-commercial light duty FCVs and fuel cell buses have many safety systems that work independently and together to protect the safety of the occupants and their surroundings. In the event of an impact, fuel leak or operation outside of normal parameters, sensors isolate the high voltage and hydrogen storage systems. The following is a summary of these systems (L= Light Duty Fuel Cell Vehicle and B=Fuel Cell Bus):

1. *Hydrogen sensors (L,B) — Sensors located throughout the vehicle*



(including the passenger cabin) detect the presence of hydrogen. If a sensor detects a leak, the solenoids that default to a closed position in the hydrogen tank close locking high pressure hydrogen in the tanks. At the same time, relays that default to an open position in the electrical system open to isolate high voltage sources. (Figure 8)

2. Sensors on fuel cell buses are placed beneath roof canopies and in engine compartments, and are linked to an on-board alarm system that sounds at concentrations as low as 0.2% in air. Upon triggering a sensor, the control system can alert the driver by way of dashboard lights, a message display center or other means. Dedicated leak indicators may concurrently display the measured percentage of hydrogen concentrations. See individual bus diagrams for exact information.
3. Impact sensors (L,B) — FCVs use inertia-based sensors, similar to air bag sensors, to detect a vehicle impact. In the event of an impact, the high pressure hydrogen storage and electrical systems will be isolated.
4. Thermally Activated Pressure Relief Device (L,B) — In case of a fire near a vehicle's hydrogen tanks, a device integrated into the assembly of each fuel tank is designed to release the hydrogen (in a controlled manner) from the tank into the atmosphere through a vent. This prevents a tank rupture due to overpressure (over-temperature). This device activates (opens) when a significant temperature build-up near or around the tank, melting a fusible metal plug and opening the device, allowing the tank to vent rapidly. If a PRD/TRD activates, you will usually hear a "bang" followed by a loud hissing sound. The tank will empty in 2-3 minutes.
5. Fire suppression system (B) — Some transit buses include a fire suppression system that will detect and extinguish fires. When the sensor is triggered, the control system alerts the driver by way of dashboard lights, a message display center or other means and shuts down the engine. After the vehicle is shut off, single-shot fire retardants may be released into one or more zones associated with the triggered sensor. Fire retardants do not discharge into the vehicle passenger compartment. A very loud sound accompanies a retardant discharge.  
  
A cloud of dry chemical retardant dust may exit the vehicle from the discharge areas. Avoid breathing the dry chemical dust as it will irritate throat and lungs. In most cases, the fire suppression system is active at all times unless the vehicle battery knife switches are open (disconnected). Some types of sensors can also detect high heat. Fuel cell buses may include thermal wire wound around the fuel cell stacks that are designed to short when melted, signaling the control system.
6. Emergency shutoff button or emergency shutdown device (L,B) — Early prototype light duty FCVs may have a manual shutoff switch in the vehicle to give the passenger/driver an additional method to shut down the vehicle and isolate the high pressure hydrogen storage and high voltage sources. A fuel cell bus normally contains an emergency



Hydrogen Sensor used in hydrogen powered vehicles.

*shutdown device (ESD) switch on the control panel near the driver and at least one externally located shutdown device switch, usually in the back of the bus with the electrical components. These switches enable the engine to be shut down from more than one location and may allow restart from the exterior of the bus. Depressing any ESD switch shuts down the low voltage system and disconnects the high pressure hydrogen. If an electrical problem with the high voltage system occurs, some buses may automatically shut down after several seconds. For clarity and simplicity, the bus emergency response diagrams refer to all shutdown device switches as ESD switches.*

7. 12 -Volt battery cable & key-off (L,B)—As with conventional vehicles, disconnecting a 12-volt battery cable and turning the key to the 'off' position shuts down the vehicle and, in the case of FCVs, isolates the high pressure hydrogen and high voltage sources.

Vehicle safety systems are configured in fail-safe designs, meaning that the default (un-powered) position for valves controlling hydrogen flow from the storage systems is “closed,” and the default position of voltage relays is “open.” All system operations monitors must be within normal ranges to close voltage relays and open the valves to allow hydrogen to flow from the fuel tanks.

### Hydrogen Refueling

As mentioned in a previous section, hydrogen fuel stations are in the planning and development process in key metropolitan areas of California with a focus on San Francisco Bay Area, Sacramento, Los Angeles and Orange County. Hydrogen stations are not a “one-size-fits-all” technology. Some stations can make hydrogen fuel on site by reforming natural gas or electrolyzing water. Other stations dispense hydrogen made at a central production facility which is trucked to the on-site storage tank. Some stations will only dispense hydrogen fuel while others will dispense it along side other fuels. For larger applications like fleet vehicles, an on-site stationary fuel cell system can make electricity and heat for buildings, as well as hydrogen for fleet vehicles.

Commercial refueling stations will have the same safety features, remote emergency shut-off, breakaway protection, and pump protection, as conventional fuel stations.

### Fuel Cell Vehicles Emergency Response

Approach a fuel cell vehicle the way you approach a conventional vehicle. If possible, position the responding apparatus up hill, upwind, and away from the vehicle. Follow the standard vehicle approach method (45 degree approach angle) taking into account the direction of the vehicle’s PRD. Reference individual manufacturer emergency response



*A Fuel Cell Bus pulls in to a Hydrogen fuel station to refuel.*

Diagrams for location and direction of vent. The standard operating procedures should also include:

- ❖ Listen for leaking hydrogen (loud hissing)
- ❖ Identify vehicle type (note blue diamond sticker)
- ❖ Confirm vehicle is off (key off, cut 12V negative cable)
- ❖ Remove fuel spills, conventional vehicles and ignition sources from FCV
- ❖ If safe, let any hydrogen fires burn; protect exposures
- ❖ Avoid using spreaders for rocker panel purchase point; if needed, use a cradle for the ram
- ❖ Do not cut high voltage or hydrogen lines

### Non-Injury Accidents

Wear full protective clothing as required for any vehicle emergency. If available, use combustible gas detectors to check for system leaks. Maneuver emergency response vehicles upwind of the disabled vehicle and approach the vehicle away from the PRD vent location. Please see model-specific diagrams for information on vehicles in your area.

### FCV Fires

Wear full protective clothing including self contained breathing apparatus (SCBA). If working directly with the vehicle use high-voltage rubber gloves and use static dissipative equipment. This equipment provides the essential protection for handling electrical components, flammable gas and hazardous fumes.

Hydrogen fires do not have a visible flame and generate little smoke. However, combustible material in or near the hydrogen flame, and particles in the air will likely render a visible flame and give off smoke. Use ultra-violet and/or infra red (IR) detectors, if available, to scan for invisible hydrogen flames. If no flames are present, scan the vehicle with a hydrogen leak detector (combustible gas detector rated for hydrogen), if available. Do not extinguish hydrogen fires unless the leak feeding the flame can be stopped. If safe to do so, allow the gas to burn out and protect exposures.

### Multi-Vehicle Accidents

If a fuel cell vehicle and an internal combustion engine vehicle are involved in a collision, move the internal combustion engine vehicle away from the fuel cell vehicle when it is safe to do so. If gasoline or diesel fuel spills near a fuel cell vehicle, spray the spilled fuel with foam to render the fuel inert.



*The futuristic looking Proterra Fuel Cell Bus is being test marketed in Burbank, CA.*

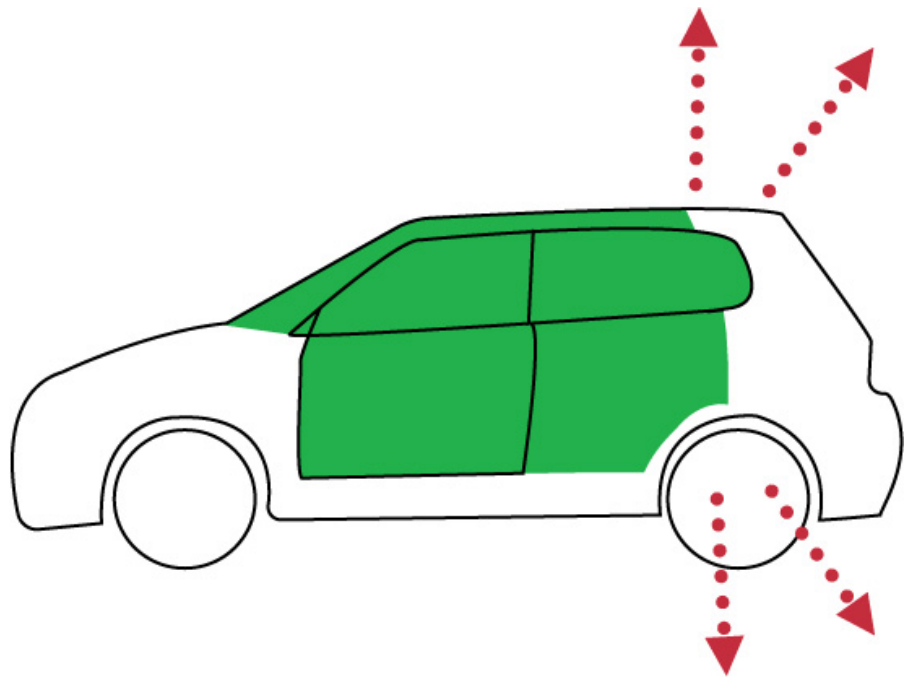
### Fuel Cell Bus Accidents

In the event of a fuel cell bus incident, the bus driver will, if possible, follow shut down procedures provided by the transit agency. Passengers will exit through the bus doors and emergency exits, as appropriate and when it is determined safe. Move passengers to a safe location upwind and away from the bus.

### Rescue/ Extrication

Before attempting to rescue occupants (patients) from an FCV or moving a damaged vehicle, check the following:

- ❖ The vehicle is turned off or no longer running
- ❖ Look for a white cloud near the vehicle, an indication of a liquid hydrogen release



*Hydrogen gas is vented through the wheel wells or through the roof of fuel cell and hydrogen fueled vehicles.*

- ❖ You do not hear a loud hissing, similar to a fire extinguisher or high pressure air hose, an indication of a gaseous hydrogen release

If you need to extricate a patient, follow standard procedures with additional consideration for the hydrogen and electrical systems. If you need to cut into an FCV (with a Hurst Tool, etc.) do not cut crucial components of the fuel cell system that include the hydrogen storage system and high voltage electrical storage (batteries or ultra capacitors). These components are usually under the flooring or in the front compartment (“under the hood”) of the vehicles.



In the case of an impact and/or a vehicle fire, approach an FCV away from the location of the PRD/TRD vent. Do not stand near or in the stream of a controlled release. This is especially important if the vehicle is on fire.

### Hydrogen Gas Releases

A FCV is designed to be as safe as or safer than conventional vehicles. In the event of an impact, impact sensors similar to those used in an airbag system deactivate the high voltage and high pressure hydrogen systems.

Take extra care if a vehicle is on fire or you hear a loud hissing sound from the vehicle. If a vehicle leaks hydrogen or the PRD/TRD activates, the vehicle's fuel tank will empty in 2-3 minutes and the hydrogen will rapidly dissipate in the atmosphere.

When the PRD/TRD releases you will hear a "bang" followed by a loud hissing sound (lasting only 2-3 minutes), similar to the sound of a discharging fire extinguisher. If you hear an audible hissing sound from a location other than the PRD/TRD then hydrogen is escaping from another component of the vehicle.

If released hydrogen ignites, an extended, near invisible flame accompanied by a loud hissing sound can be observed and detected with positive readouts from combustible gas detectors capable of measuring hydrogen. Hydrogen flames are visible to UV/IR detection equipment.

### The California Fuel Cell Partnership

The material contained in this section was provided by the California Fuel Cell Partnership. The California Fuel Cell Partnership is a collaboration of 31 member organizations working towards the commercialization of FCVs.

Through a "learn by doing" approach to vehicle and infrastructure demonstration, CaFCP members will continue to promote the development of practical codes and standards for FCVs and hydrogen fuel stations, and to help prepare local communities for the vehicles and fuel by educating local officials, including emergency response personnel. Members will also continue to expand public awareness through education and outreach activities, consistent with the pace of technology development.

To find more information about the California Fuel Cell Partnership and its members visit [www.cafc.org](http://www.cafc.org).



